



Collection Systems O&M Fact Sheet Trenchless Sewer Rehabilitation

DESCRIPTION

As the infrastructure in the United States ages, increasing importance is being placed on rehabilitating the nation's wastewater treatment collection systems. Cracks, settling, tree root intrusion, and other disturbances that develop over time deteriorate pipe lines and other conveyance structures that comprise wastewater collection systems. These deteriorating conditions can increase the amount of inflow and infiltration (I/I) entering the system, especially during periods of wet weather. Increased I/I levels create an additional hydraulic load on the system and thereby decrease its overall capacity. In addition to I/I flow, storm water may enter the wastewater collection system through illegal connections such as down spouts and sump pumps. If the combination of wastewater, infiltration, and illegal storm water connections entering the wastewater treatment plant exceeds the capacity of the system at any point, untreated wastewater may be released into the receiving water. This bypass of untreated wastewater, known as a Sanitary Sewer Overflow (SSO), may adversely affect human health as well as impair the usage and degrade the water quality of the receiving water.

Under the traditional method of sewer relief, a replacement or additional parallel sewer line is constructed by digging along the entire length of the existing pipeline. While these traditional methods of sewer rehabilitation require unearthing and replacing the deficient pipe (the dig-and-replace method), trenchless methods of rehabilitation use the existing pipe as a host for a new pipe or liner. Trenchless sewer rehabilitation techniques offer a method of correcting pipe deficiencies that requires less restoration and causes less disturbance and

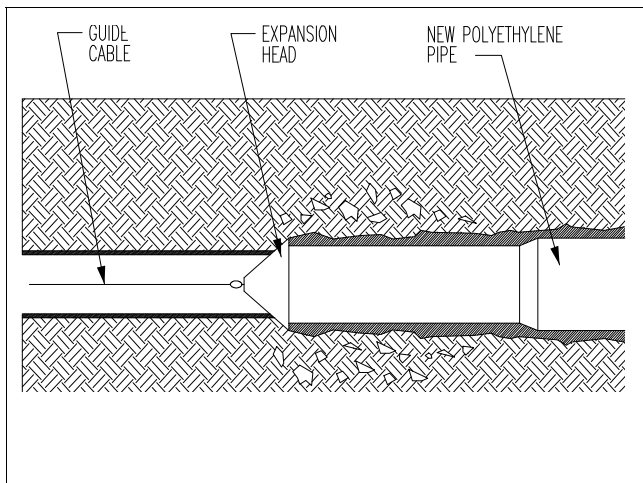
environmental degradation than the traditional dig-and-replace method. Trenchless sewer rehabilitation methods include:

- Pipe Bursting, or In-Line Expansion;
- Sliplining;
- Cured-In-Place Pipe; and
- Modified Cross Section Liner.

These alternative techniques must be fully understood before they are applied. These four sewer rehabilitation methods are described further in the following sections.

Pipe Bursting or In-Line Expansion

Pipe bursting, or in-line expansion, is a method by which the existing pipe is forced outward and opened by a bursting tool. The Pipebursting™ method, patented by the British Gas Company in 1980, was successfully applied by the gas pipelines industry before its applicability was identified by other underground utility agencies. Over the last two decades, other methods of in-line expansion have been patented as well. During in-line expansion, the existing pipe is used as a guide for inserting the expansion head (part of the bursting tool). The expansion head, typically pulled by a cable rod and winch, increases the area available for the new pipe by pushing the existing pipe radially outward until it cracks. The bursting device pulls the new pipeline behind itself. The pipe bursting process is illustrated in Figure 1. Various types of expansion heads, categorized as static or dynamic, can be used on the bursting tool to expand the existing pipeline. Static heads, which have no



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FIGURE 1 THE PIPE BURSTING PROCESS

moving internal parts, expand the existing pipe only through the pulling action of the bursting tool. Unlike static heads, dynamic heads provide additional pneumatic or hydraulic forces at the point of impact. Pneumatic heads pulsate internal air pressure within the bursting tool, while hydraulic heads expand and collapse the head. While the dynamic head pulsates or expands and contracts, the bursting device is pulled through the existing pipeline and breaks up the existing pipe, replacing it with the new pipe directly behind it. Dynamic heads are often required to penetrate difficult pipe materials and soils. However, because dynamic heads can cause movement of the surrounding soils-resulting in additional pressure and ground settlement-static heads are preferred where pipe and soil conditions permit.

During the pipe bursting process, the rehabilitated pipe segment must be taken out of service by re-routing flows around it. After the pipe bursting is completed, laterals are re-connected, typically with robotic cutting devices.

Sliplining

Sliplining is a well-established method of trenchless rehabilitation. During the sliplining process, a new liner of smaller diameter is placed inside the existing pipe. The annular space, or area between the existing pipe and the new pipe, is typically grouted to prevent leaks and to provide structural integrity. If the annulus between the sections is not

grouted, the liner is not considered a structural liner. Continuous grouting of the annular space provides a seal. Grouting only the end-of-pipe sections can cause failures and leaks.

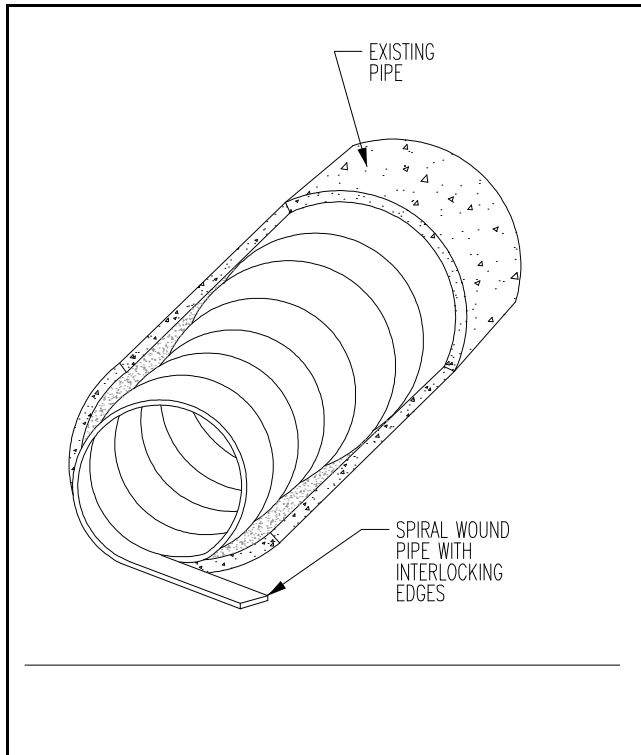
In most sliplining applications, manholes cannot function as proper access points to perform the rehabilitation. In these situations, an insertion pit must be dug for each pipeline segment. Because of this requirement, in most applications, sliplining is not a completely trenchless technique. However, the excavation required is considerably less than that for the traditional dig-and-replace method. System and site conditions will dictate the amount of excavation spared.

Methods of sliplining include continuous, segmental and spiral wound. All three methods require laterals to be re-connected by excavation or by a remote-cutter. In continuous sliplining, the new pipe, joined to form a continuous segment, is inserted into the host pipe at strategic locations. The installation access point, such as a manhole or insertion pit, must be able to handle the bending of the continuous pipe section.

Installation by the segmental method involves assembling pipe segments at the access point. Sliplining by the segment method can be accomplished without rerouting the existing flow. In many applications, the existing flow reduces frictional resistance and thereby aids in the installation process. Spiral wound sliplining is performed within a manhole or access point by using interlocking edges on the ends of the pipe segments to connect the segments. The spiral wound pipe is then inserted into the existing pipe as illustrated in Figure 2.

Cured-In-Place Pipe

During the cured-in-place pipe (CIPP) renewal process, a flexible fabric liner, coated with a thermosetting resin, is inserted into the existing pipeline and cured to form a new liner. The liner is typically inserted into the existing pipe through an existing manhole. The fabric tube holds the resin in place until the tube is inserted in the pipe and ready to be cured. Commonly manufactured resins include unsaturated polyester, vinyl ester, and



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FIGURE 2. SPIRAL WOUND SLIPLINING PROCESS

epoxy, with each having distinct chemical resistance to domestic wastewater.

The CIPP method can be applied to rehabilitate pipe lines with defects such as cracks, offset joints, and structurally deficient segments. The thermosetting resin material bonds with the existing pipe materials to form a tighter seal than most other trenchless techniques. The two primary methods of installing CIPP are winch-in-place and invert-in-place. These methods are used during installation to feed the tube through the pipe. The winch-in-place method uses a winch to pull the tube through the existing pipeline. After being pulled through the pipeline, the tube is inflated to push the liner against the existing pipe walls. The more typically applied inversion-in-place method uses gravity and either water or air pressure to force the tube through the pipe and invert it, or turn the tube inside out. This process of inversion presses the resin-coated tube against the walls of the existing pipe. During both the winch-in-place and inversion-in-place methods, heat is then circulated through the tube to cure the resin to form a strong bond between the tube and the existing pipe. A typical CIPP process

by the water-inversion method is illustrated in Figure 3.

Under both CIPP methods, as the liner expands to fit the new pipe, dimples occur in the line where the laterals exist. Dimples in the line can be found by TV inspection or robotic equipment. In some applications, a Tee is placed at the junction before rehabilitation begins. Tees enable junctions to be easily identified and modified after the pipeline has been re-lined. Laterals are typically reinstated with robotic cutting devices, or, for large-diameter pipes, by manually cutting the liner.

Modified Cross Section Lining

The modified cross section lining methods include deformed and reformed methods, swagelining™, and rolldown. These methods either modify the pipe's cross sectional profile or reduce its cross-sectional area so that the liner can be extruded through the existing pipe. The liner is subsequently expanded to conform to the existing pipe's size.

During deformed and reformed pipeline renewal, a new flexible pipe is deformed in shape and inserted into the host pipe. While the method of deforming the flexible pipe varies by manufacturer, with many processes referred to as fold and form methods, a typical approach is to fold the new liner into a "U" shape, reducing the pipe's diameter by about 30 percent. After the liner is pulled through the existing line, the liner is heated and pressurized to conform to the original pipe shape. A typical deformed and reformed cross-section is illustrated in Figure 4.

Another method of obtaining a close fit between the new lining and existing pipe is to temporarily compress the new liner before it is drawn through the existing pipeline. The swagelining™ and rolldown processes use chemical and mechanical means, respectively, to reduce the cross-sectional area of the new liner.

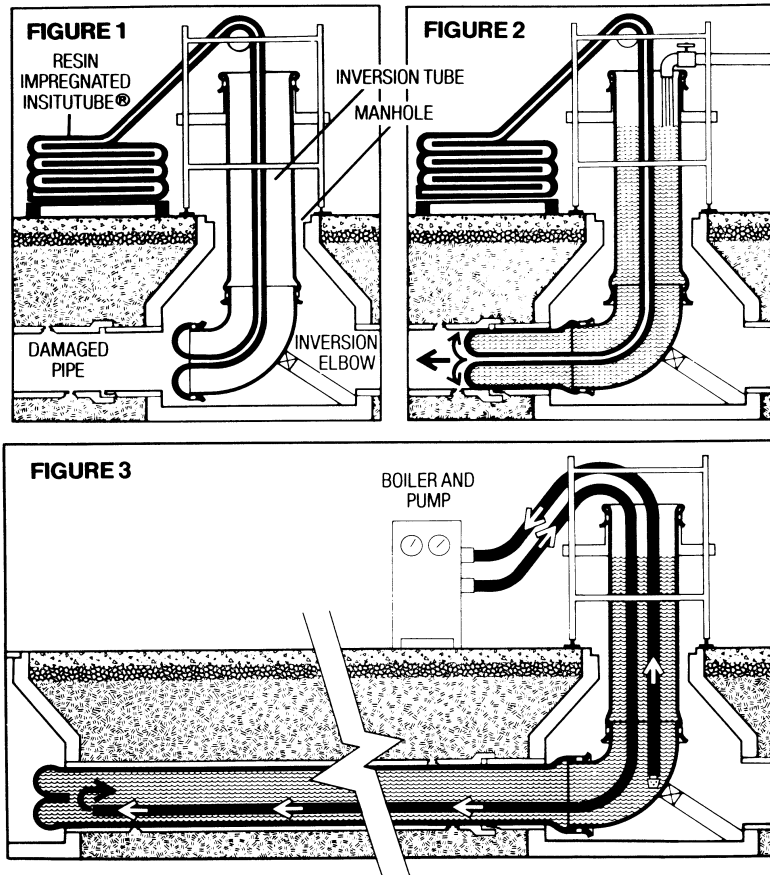
During swagelining™, a typical drawdown process, the new liner is heated and subsequently passed through a reducing die. A chemical reaction between the die and liner material temporarily reduces the liner's diameter by 7 percent to 15

How Insituform® is installed

Figure 1. A special needled felt reconstruction tube, Insitutube®, coated on the outside, is custom engineered and manufactured to fit the damaged pipe exactly. It is impregnated with a liquid thermosetting resin and lowered into a manhole through an inversion tube. One end of the Insitutube is firmly attached to the lower end of the inversion tube elbow.

Figure 2. The inversion tube is then filled with water. The weight of the water pushes the Insitutube into the damaged pipe and turns it inside out, while pressing the resin impregnated side firmly against the inside walls of the old pipe. The smooth coated side of the Insitutube becomes the new interior surface of the pipe.

Figure 3. After the Insitutube is inverted through the old pipe to the desired length, the water is circulated through a boiler. The hot water causes the thermosetting resin to cure within a few hours, changing the pliable Insitutube into a hard, structurally sound, pipe-within-a-pipe, Insutpipe™. It has no joints or seams and is usually stronger than the pipe it replaced. The ends are cut off and the inversion tube and scaffolding are removed. Normally, there are no messy excavation repairs to be made since most work is done without digging or disruption.



Source: Iseley and Najafi, 1995 (from Insituform®)

FIGURE 3 A TYPICAL CURED-IN-PLACE PIPE INSTALLATION PROCEDURE

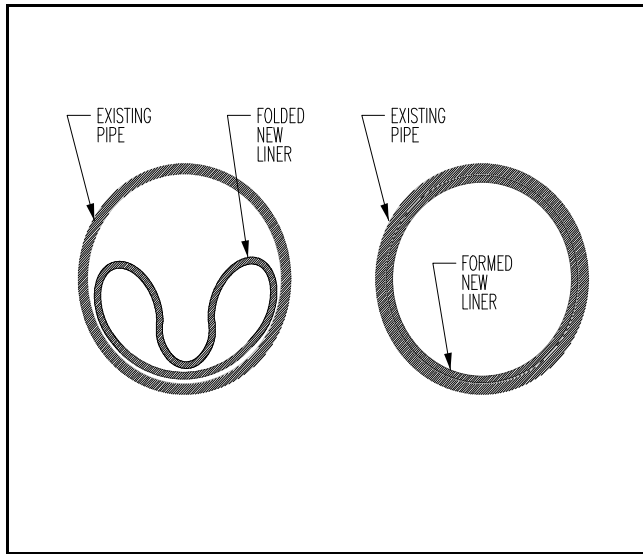
percent and allows the liner to be pulled through the existing pipe. As the new liner cools, it expands to its original diameter. The rolldown process uses a series of rollers to reduce the pipe liner's diameter. As in deform-and-reform methods, heat and pressure are applied to the expand the liner to its original pipe diameter after it has been pulled through the existing pipe.

Unlike CIPP, modified cross section methods do not make use of resins to secure the liner in-place. Lacking resin-coated lining, these methods do not have the curing time requirement of CIPP. A tight fit is obtained when the folded pipe expands to the host pipe's inside diameter under applied heat and pressure. As with the CIPP method, dimples are formed at lateral junctions and similar methods of reconnecting the laterals can be employed. Materials typically used for modified cross section

linings include Polyvinyl Chloride (PVC) and High Density Polyethylene (HDPE).

Trenchless sewer rehabilitation methods are now routinely applied to wastewater collection system improvement projects in the United States and many other countries. Trenchless sewer rehabilitation has been successfully applied by both large municipalities such as New York, NY; Los Angeles, CA; Boston, MA; Miami, FL; and Houston, TX; and smaller municipalities such as Baton Rouge, LA; Madison, WI; and Amarillo, TX. Kramer and Thomson (1997) estimate that the market value for sewer and pressure pipe rehabilitation projects will be \$5 billion dollars world-wide in the year 2000.

In many municipalities, sewer rehabilitation projects are an essential part of operation and



Source: Created by Parsons Engineering Science, Inc., 1999.

FIGURE 4 DEFORMED AND REFORMED LINERS

maintenance (O&M) programs for the collection system. For example, as part of an O&M program focused on pro-active maintenance, Fairfax County, Virginia, has identified two older sewersheds for rehabilitation. All trunk and main lines within each sewershed are television inspected. Results of the TV inspection are used to prioritize cleaning needs and to help determine appropriate rehabilitation measures. Projects within the targeted sewersheds have utilized the CIPP and fold-and-form rehabilitation methods.

In an effort to monitor the effectiveness of the rehabilitation efforts, the department installed permanent and temporary meters in these two sewersheds. Fairfax County's focused approach to maintenance has reduced average flows to the wastewater treatment plant (WWTP) despite several years of above- normal rainfall.

APPLICABILITY

While trenchless techniques may be applied to rehabilitate existing pipelines in a variety of conditions, they are particularly valuable in urban environments where construction impacts are particularly disruptive to businesses, homeowners, and automotive and pedestrian traffic. Other underground utilities and existing infrastructure are an obstacle in the traditional dig and replace method, and trenchless techniques are widely

applied where these are present. Most trenchless techniques are applicable to both gravity and pressure pipelines. Many trenchless methods are capable of performing spot repairs as well as manhole to manhole lining.

For most applications, trenchless sewer rehabilitation techniques require less installation time-and therefore less pump-around time- than traditional dig-and-replace methods. Installation time can be critical in deciding between trenchless sewer rehabilitation methods and dig- and-replace methods. For example, when considering sewer repair or replacement options for a critical force main crossing the Elbe River in Heidenau, Germany, city officials determined that the line could not be out of service for more than 12 days (Saccogna, 1998). As a result of this time constraint, as well as reduced disruption to riverboat traffic, city officials chose to rehabilitate the sewer using the swagelining™ process. The successfully rehabilitated sewer was out of service only eight days.

Trenchless sewer rehabilitation can be performed to increase the hydraulic capacity of the collection system. While pipe bursting typically yields the largest increase in hydraulic capacity, rehabilitation by other trenchless methods may also increase hydraulic capacity, by reducing friction. A hydraulic analysis of the pre- and post-rehabilitation conditions can be performed to evaluate the impact on collection system capacity. In general, the hydraulic analysis is performed by municipal engineers and/or consultants who prepare specifications for contractors.

Each of the trenchless rehabilitation methods described has been used for various applications over a range of pipe sizes and lengths. A comparison of trenchless techniques is shown in Table 1.

ADVANTAGES AND DISADVANTAGES

By reducing I/I levels in the collection system, trenchless rehabilitation projects can assist communities in complying with the EPA's Clean Water Act and thereby protect the aquatic integrity of receiving water-bodies from potentially high

TABLE 1 A COMPARISON OF VARIOUS SEWER REHABILITATION TECHNIQUES

Method:		Diameter Range (mm)	Maximum Installation (m)	Liner Material
In-Line Expansion	Pipe Bursting	100-600 (4-24 in.)	230 (750 ft.)	PE, PP, PVC, GRP
Sliplining	Segmental	100 - 4000 (4-158 in.)	300 (1,000 ft.)	PE, PP, PVC, GRP (-EP & -UP)
	Continuous	100 -1600 (4-63 in.)	300 (1,000 ft.)	PE, PP, PE/EPDM, PVC
	Spiral Wound	150 -2500 (6-100 in.)	300 (1,000 ft.)	PE, PVC, PP, PVDF
Cured-In-Place Product Linings	Inverted-In-Place	100-2700 (4-108 in.)	900 (3,000 ft.)	Theromaset Resin/Fabric Composite
	Winched-In-Place	100 -1400 (4-54 in.)	150 (500 ft.)	Theromaset Resin/Fabric Composite
	Spray-on-Linings	76-4500 (3-180 in.)	150 (500 ft.)	Epoxy Resins/Cement Mortar
Modified Cross- Section Methods	Fold and Form	100-400 (4-15 in.)	210 (700 ft.)	PVC (thermoplastics)
	Deformed/Reformed	100-400 (4-15 in.)	800 (2,500 ft.)	HDPE (thermoplastics)
	Drawdown	62-600 (3-24 in.)	300 (1,000 ft.)	HDPE, MDPE
	Rolldown	62-600 (3-24 in.)	300 (1,000 ft.)	HDPE, MDPE
	Thin-walled lining	500-1,100 (20-46 in.)	960 (3,000 ft.)	HDPE
Internal Point Repair	Robotic Repair	200-760 (8-30 in.)	N/A	Exopy Resins Cement Mortar
	Grouting/Sealing & Spray-on	N/A	N/A	Chemical Grouting
	Link Seal	100-600 (4-24 in.)	N/A	Special Sleeves
	Point CIPP	100-600 (4-24 in.)	15 (50 ft.)	Fiberglass/Polyester, etc.

Note: Spiral wound sliplining, robotic repair, and point CIPP can only be used only with gravity pipeline.
All other methods can be used with both gravity and pressure pipeline.

EPDM = Ethylene Polypelene Diene Monomer
 GRP = Glassfiber Reinforced Polyester
 HDPE = High Density Polyethylene
 MDPE= Medium Density Polyethylene
 PE = Polyethylene
 PP = Polypropylene
 PVC = Poly Vinyl Chloride
 PVDF = Poly Vinylidene Chloride

Source: Iseley and Najafi (1995)

pollutant concentrations by reducing SSOs. In addition to potential improvements in receiving water-bodies, trenchless sewer rehabilitation requires substantially less construction work than traditional dig-and-replace methods. In wetland areas and areas with established vegetation, construction influences can be especially harmful to the plant and aquatic habitat. Underground utility construction can disrupt citizens living and working in areas near the construction zone. Trenchless sewer rehabilitation, with the potential to reduce surface disturbance over traditional dig- and-replace methods, can reduce the number of traffic and pedestrian detours, spare tree removal, decrease construction noise, and reduce air pollution from construction equipment. In addition to these benefits, reducing the amount of underground construction labor and surface construction zone area confines work zones to a limited number of access points, reducing the area where safety concerns must be identified and secured. Rehabilitation techniques should be selected based on site constraints, system characteristics, and project objectives. A comparison of economic, cultural and social costs of sewer rehabilitation with those of traditional dig-and-replace methods can

help determine whether or not a trenchless sewer rehabilitation is suitable and economically feasible for a particular site. Because some digging may be required for point repairs, construction limitations should be evaluated when deciding whether trenchless sewer rehabilitation techniques can be applied. If there are major changes in cross section between manholes or if the existing alignment, slope, or pipe bedding material must be changed, each line must be rehabilitated as an independent segment, necessitating even more digging. Specific limitations of each trenchless rehabilitation method are listed in Table 2. As seen, the sliplining, deform-and- reform methods, and CIPP methods will reduce the pipe diameter tending to decrease the hydraulic capacity of the sewer. The rehabilitated pipeline, however, may be less rough than the original. The roughness coefficient depending on the liner material. New high performance plastic materials tend to reduce pipe roughness against aged concrete materials. Additionally, the hydraulic capacity may be modified during rehabilitation as groundwater intrusion is inadvertently redirected to unlined side sewers. An evaluation may be performed to determine whether the change in pipe friction and

TABLE 2 LIMITATIONS OF TRENCHLESS SEWER REHABILITATION

Method	Limitations
Pipe Bursting	<ul style="list-style-type: none"> Bypass or diversion of flow required Insertion pit required Percussive action can cause significant ground movement May not be suitable for all materials
Sliplining	<ul style="list-style-type: none"> Insertion pit required Reduces pipe diameter Not well suited for small diameter pipes
CIPP	<ul style="list-style-type: none"> Bypass or diversion of flow required Curing can be difficult for long pipe segments Must allow adequate curing time Defective installation may be difficult to rectify Resin may clump together on bottom of pipe Reduces pipe diameter
Modified Cross Section	<ul style="list-style-type: none"> Bypass or diversion of flow required The cross section may shrink or unfold after expansion Reduces pipe diameter Infiltration may occur between liner and host pipe unless sealed Liner may not provide adequate structural support

groundwater redirection will offset the decrease in pipe diameter and meet project objectives for an increase in peak flow and/or reduction in SSOs. Most trenchless rehabilitation applications require laterals to be shut down for a 24 hour period. Coordinating shut-downs with property owners can be a difficult and unpopular task. Unforeseen conditions can increase construction time and increase the risk and responsibility to the client and contractor. For example, during a rehabilitation project in Norfolk, Virginia, pipe bursting had to be coordinated with the relocation of a nearby electrical substation and the rerouting of flow from a sanitary force main found in a manhole where an insertion pit was to be located (Small, Gidley, and Riley, 1997). In addition to these issues, numerous abandoned underground utilities which were not indicated on city or private utility records were encountered during the project. Such underground conditions are found in many other urban environments around the United States. When trenchless rehabilitation is planned, public works projects and utility work by other agencies should be coordinated with sewer rehabilitation projects.

PERFORMANCE

The performance of trenchless techniques in reducing I/I can be determined through flow measurements taken before and after the rehabilitation. Effectiveness is typically calculated by correlating flow measurements with precipitation data to determine the peak rate and volume of I/I entering the collection system. Another method of calculating I/I is to isolate the rehabilitated line and measure flows both before and after the rehabilitation.

The performance of sewer rehabilitation projects in three Northeastern Illinois communities was documented by Goumas (1995). Results of pre- and post-monitoring within these three communities indicate that I/I reductions of 49 percent, 65 percent and 82 percent were achieved. The Washington Suburban Sanitary Commission (WSSC) uses the isolation and measurement method to assess the performance of rehabilitation projects. An analysis of 98 sewer mains rehabilitated between 1989 and 1995 indicates that

I/I flow was reduced by 70 percent in the rehabilitated sewers (WSSC, 1998).

The Miami-Dade Water and Sewer Department (MDWASD) is completing one of the country's largest I/I reduction programs. The program, aimed at reducing I/I throughout the system, utilizes the fold and form, CIPP, pipe bursting, and sliplining rehabilitation techniques in conjunction with point and robotic repairs. MDWASD has already experienced success with this program; an average I/I reduction of 19 percent (20 MGD) has been achieved between January 1995 and May 1998 based on comparing plant flow and billed flow (MDWASD, 1998)

In Fairfax County, VA, between June 1994 and June 1998, wet weather flows were significantly reduced within the two sewer sheds identified in the County's focused rehabilitation program even though the program addresses only main and trunk sewer lines and does not address I/I from private laterals (Fairfax County, 1998).

These studies should only be used as an indicator of potential I/I removal. Removal rates will vary depending on the material and condition of the pipe, local soil type, groundwater flow, and other site-specific conditions.

COSTS

Cost ranges for trenchless rehabilitation of a typical size sewer main are provided in Table 3. These costs include a standard cleaning of the sewer line (major blockages and point repairs increase the cost) and inspection of the sewer line before and after the sewer is rehabilitated. Sewer rehabilitation by both trenchless and traditional dig- and-replace methods can reduce treatment and O&M costs at the receiving treatment plant by potentially eliminating I/I flows to the plant. In addition to treatment cost savings, energy costs for transporting flows to the treatment plant could also be reduced due to the reduced flow volume.

A cost comparison of trenchless and traditional sewer rehabilitation methods must consider the condition and site characteristics of the existing

TABLE 3 TYPICAL COST RANGE FOR SMALL SEWER MAINS

Technique	Pipe Diameter, mm (in.)	Cost Range, per linear meter (ft.)
Pipe Bursting	203 (8)	\$130-\$260 (\$40-\$80)
Sliplining	457 (21)	\$260-\$550 (\$80-\$170)
CIPP	203 (8)	\$80-\$215 (\$25-\$65)
Modified Cross Section	203 (8)	\$58-\$162 (\$18-\$50)

Sources: Kung'u (1998), Burkhard (1998), Cost in 1998 dollars.

These costs are an indicator of some project costs but each project cost is site-specific.

pipeline. Factors influencing the cost of a trenchless sewer rehabilitation project include:

- the diameter of the pipe;
- the amount of pipe to be rehabilitated;
- specific defects in the pipe (such as joint offsets, root intrusions, severe cracking or other defects);
- the depth of the pipe to be replaced, and changes in grade over the pipe length;
- the locations of access manholes;
- the number of additional access points that need to be excavated;
- the location of other utilities that have to be avoided during construction;
- provisions for flow by-pass;
- the number of service connections that need to be reinstated; and
- the number of directional changes at access manholes.

In general, the less the amount of excavation required for a rehabilitation operation, the more cost-effective trenchless sewer rehabilitation becomes as compared with the traditional dig-and-replace method. In addition to excavation and installation costs, sewer cleaning and inspection are

typically required before sewer rehabilitation

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